Introduction to cognitive science

Session 6: Computational modeling

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Computational models

- embody hypotheses about mechanisms and structures underlying cognition
- require theories to be operationally specified
- enable to control parameters (and gain data) inaccessible in humans

Types of models

- By paradigm/approach
  - Symbolic
  - Connectionist
  - Bayesian
  - Dynamical System
  - Multiagent system
  - Embodied (in physical robot)

Terms to be explained

- hypotheses, data, model, simulation
- model behaviour and model fit
- model parameters
- simplification
- proof-of-concept
- validation and verification

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Terms to be explained

TASK

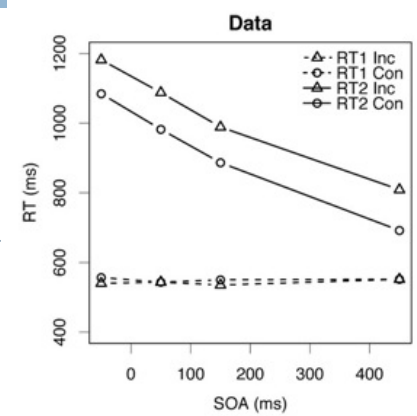
BLUE GREEN YELLOW

PINK RED ORANGE

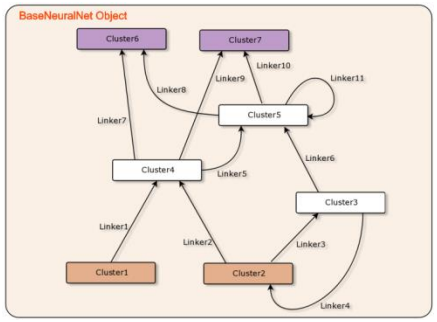
GREY BLACK PURPLE

TAN WHITE BROWN

BEHAVIOUR

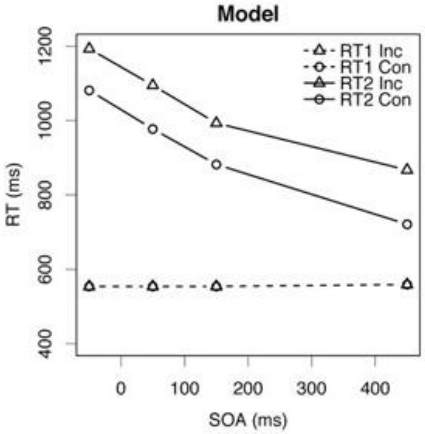


MODEL FIT

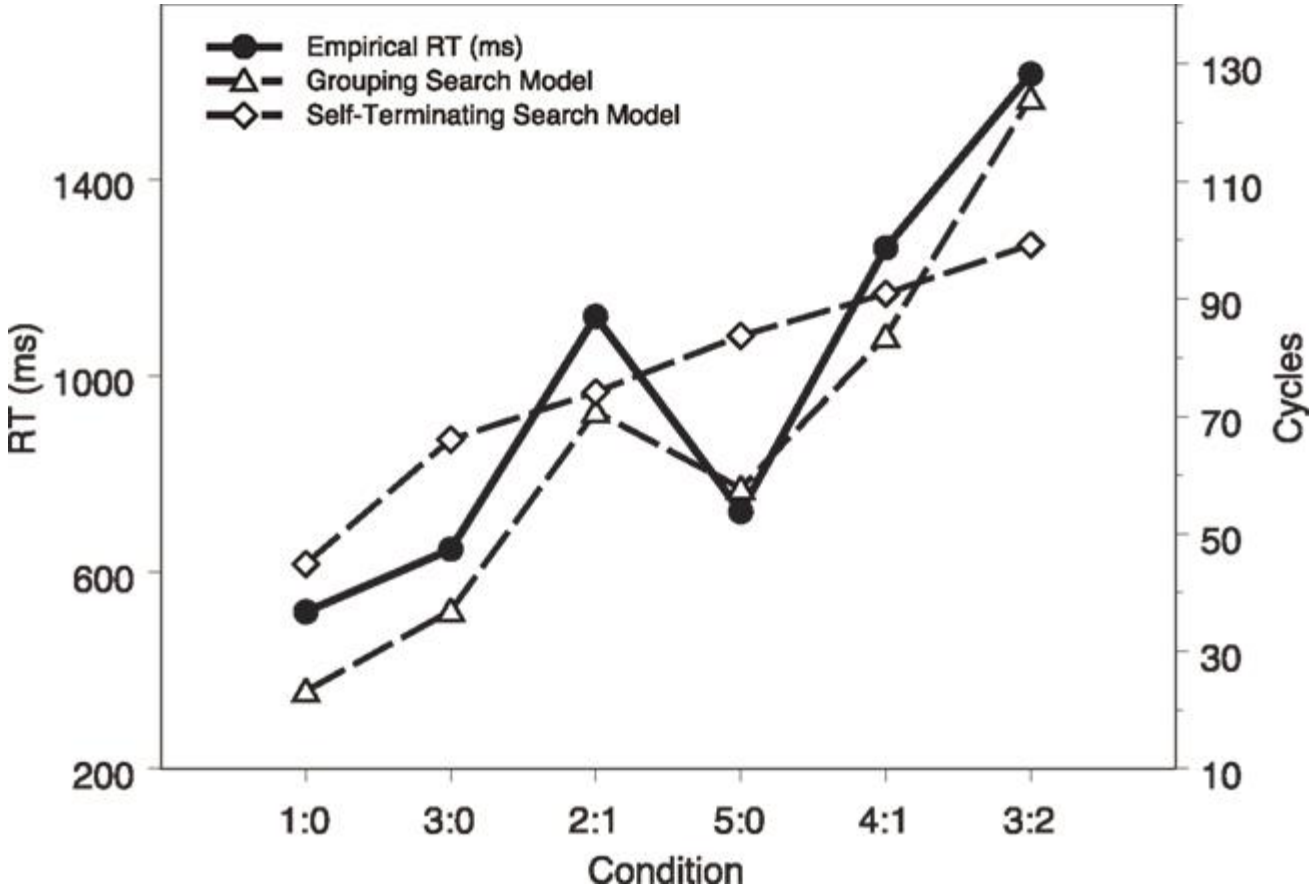


Model (HYPOTHESIS)

SIMULATION



Model fit


Empirical RT (ms)
Grouping Search Model
Self-Terminating Search Model
RT (ms)
1400
1000
600
200
Cycles
130
110
90
70
50
30
10
1:0
3:0
2:1
5:0
4:1
3:2
Condition

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Case study: models of reading aloud

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Three Levels of Description (David Marr)

1. **Computational theory**
2. **Representation and algorithm**
3. **Implementation level**

Case study: models of reading aloud

- **Modelled phenomenon:** process of transformation of visual representation (written words) into sound patterns (spoken words)
- **Empirical data to fit:** reading patterns, types of errors, reaction times in healthy readers vs. readers with various disorders (dyslexias, alexias).

Case study: models of reading aloud

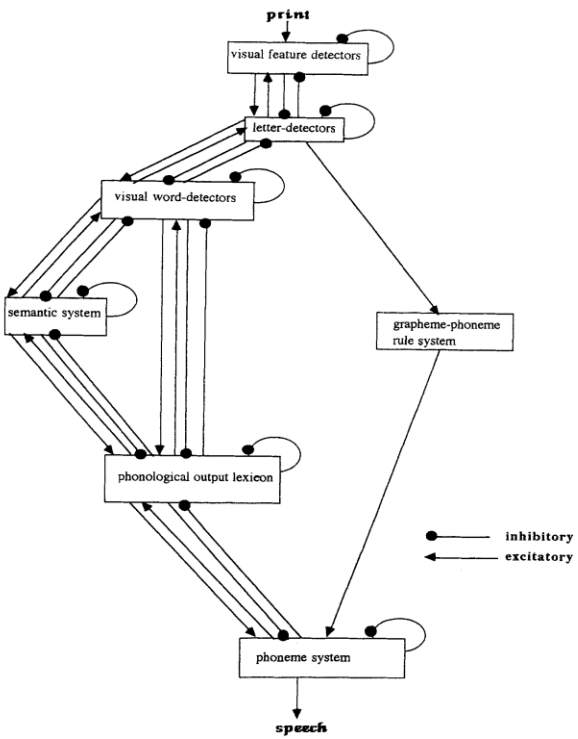
- Stimuli
  - words with regular pronunciation: *hint, mood*
  - words with irregular pronunciation: *pint, flood*
  - Non-words (pseudowords): *flernish* (but not *wstoepfteg*)
- Dyslexias
  - **Surface dyslexia:** non-words and regular words ok, irregular words impaired (regularized)
  - **Phonological dyslexia:** non-words impaired, words ok.

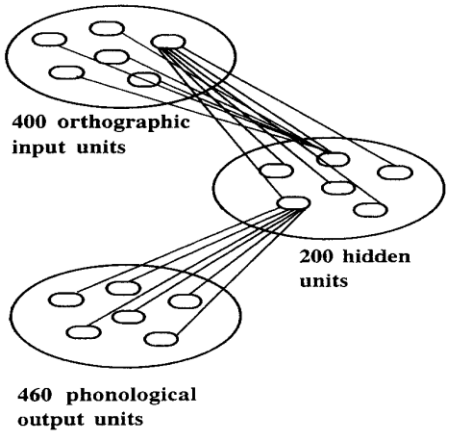
Case study: models of reading aloud

- A good model should account for:
  - reading patterns and RT for reading (or other tasks, such as lexical decision)
  - on regular and irregular words and non-words
  - in healthy readers, phonological and surface dyslectics
  - (in different languages: with shallow (e.g. Croatian) or deep (e.g. Hebrew) orthography)

Case study: models of reading aloud

- Selection of architecture:
  - dual-route model (left, Coltheart, 1985)
  - PDP models (right, Seidenberg & McClelland, 1989)





Coltheart et al. (1993): Models of Reading Aloud: Dual-Route and Parallel-Distributed-Processing Approaches, Psychological Review 100(4):589-608

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- **validation** and **verification**

Verification vs. validation

- **Verification:** whether the model implementation realizes the abstract model design
- **Validation:** whether the model design is relevant for the real system (are simplifying assumptions realistic?) and reflects its behaviour.

Which model is the best one?

- validated by fit between simulated and real behavior (consistency with the data)
- the fit is not a proof of the hypothesis (model can be falsified by data, but not proved)!
- In case of good fit, the selection criterion is often parsimony (Occam's razor)

Life cycle of a modelling project

1. Gain theoretical insight, formulate hypotheses
2. Choose a task/scenario
3. Add details, turn hypotheses about:
   - structure into model architecture design
   - processes into algorithms
   - behaviours into operationalized tests
4. Implement
5. Choose parameter values, run simulations, get results
6. Compare results with empirical data and evaluate goodness of fit
7. Vary parameters, find optimal values, iterate steps 5-7
8. Analyse the results
9. Extrapolate the results into the modelled domain to gain deeper understanding

Case study: Origin of language

- Phylogeny: Evolution of biological and cognitive predispositions
- Ontogeny: Individual language acquisition
- Glossogeny: Historical language changes

Origin of language

- Phylogeny: Evolution of biological and cognitive predispositions
  - Evolution
- Ontogeny: Individual language acquisition
  - Learning
- Glossogeny: Historical language changes
  - Cultural transmission

Origin of language

- Phylogeny: Evolution of biological and cognitive predispositions
  - Evolution: Evolutionary algorithms
- Ontogeny: Individual language acquisition
  - Learning: Machine learning, Artificial neural networks
- Glossogeny: Historical language changes
  - Cultural transmission: Multi-agent systems

Artificial evolution

- **Population** of individuals
- Each individual has a behavioural strategy (phenotype) encoded in genome (genotype)
- Individuals compete for resources (**fitness**-based **selection**)
- Multiple rounds, at the end of the round they **reproduce (mutation, cross-over)** and die

Examples

- Evolution of altruism, moral norms, etc.
- Prisoner's dilemma
- Cost matrix (Reward, Punishment, Temptation, Sucker): T>R>P>S

	C2	D2
C1	R	S
D1	T	P

	C2	D2
C1	5,5	0,3
D1	3,0	1,1

Example

- Cheating/checking (Knez, Takáč, 2014)
- Netlogo

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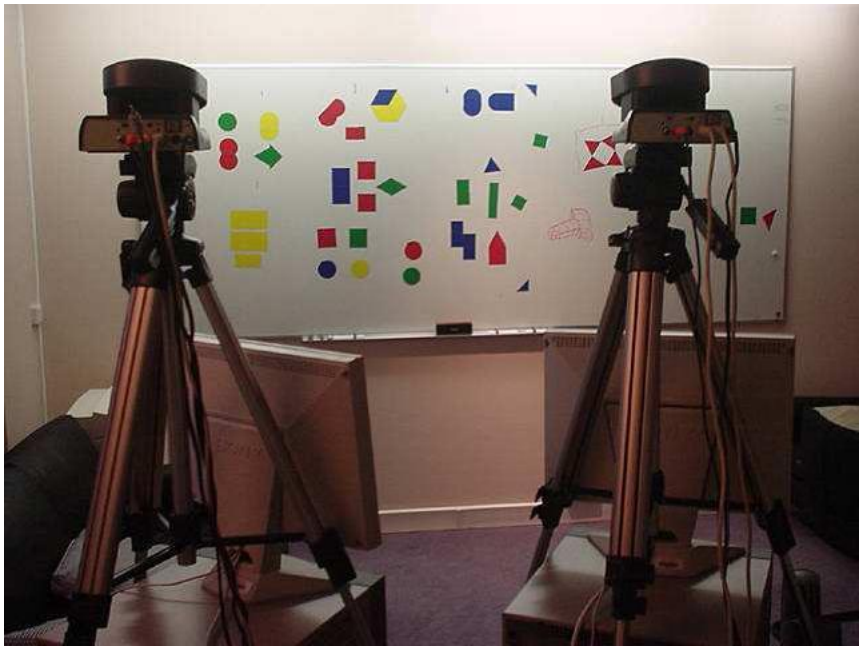
Models of cultural transmission

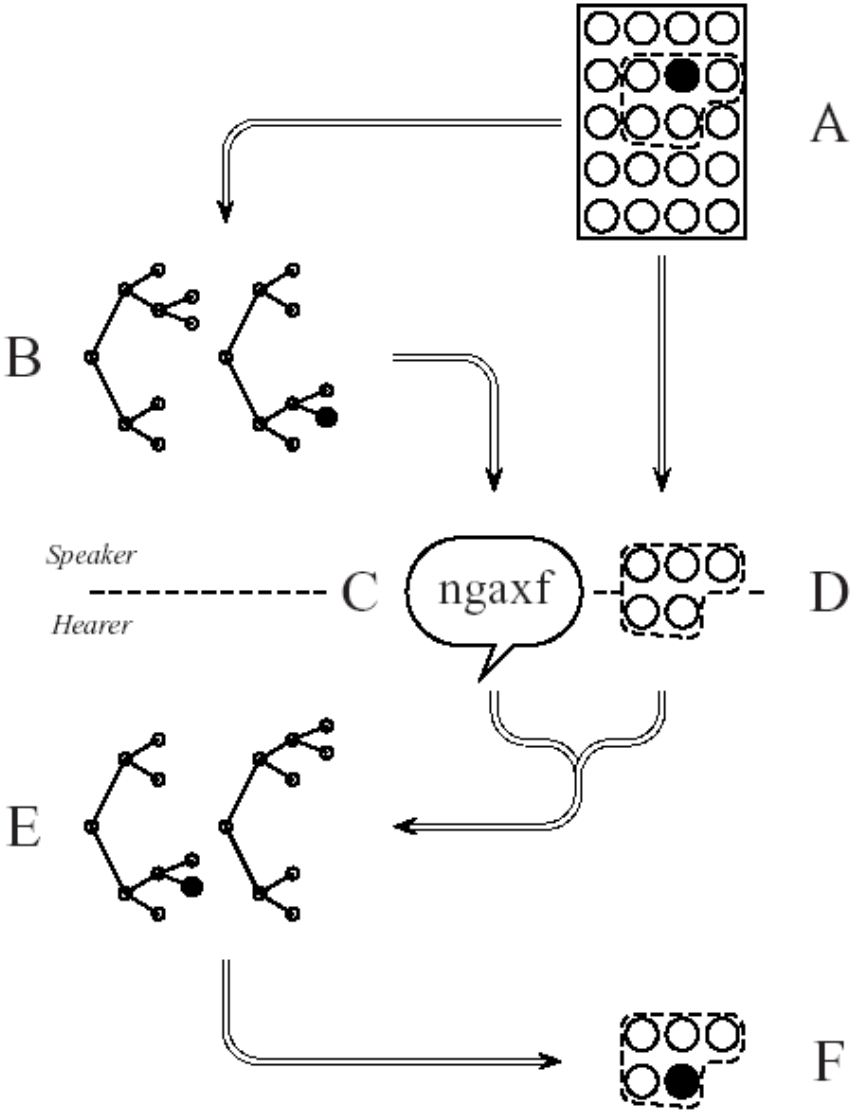
- Complex systems
- Emergence: local rules, global behaviours
- Multi-agent systems

Talking Heads (Steels, 1999)



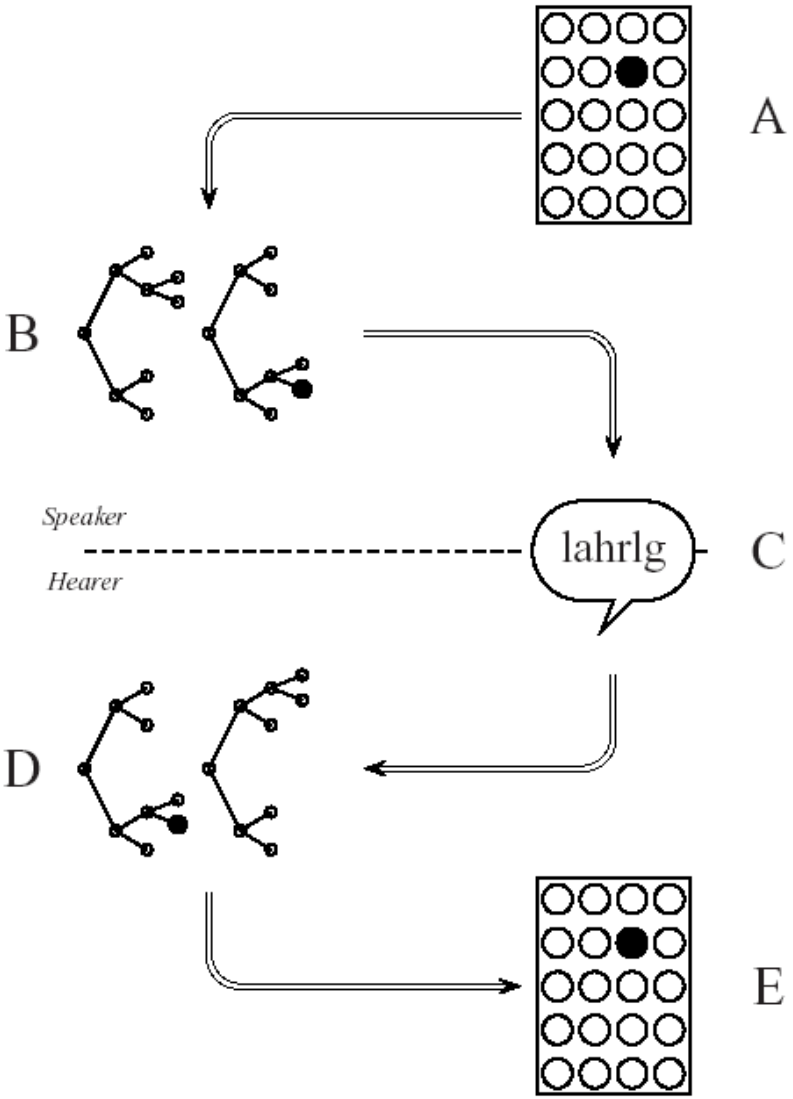
Communication

- **Speaker:**
  - context, topic, background
  - discriminating category
  - lexicalization (signal selection)
- **Hearer:**
  - Signal interpretation



Communication success

- The same referents



Questions?